FERMI GAMMA-RAY OBSERVATORY - SCIENCE HIGHLIGHTS FOR THE FIRST ± 8 MONTHS

Alexander Moiseev

CRESST/NASA GSFC and University of Maryland

for the Fermi LAT Collaboration

Fermi Observatory

Launched on June 11, 2008, from Cape Canaveral on 565 circular orbit with 25.6 inclination. Mission duration: 5 years, with the goal to extend it to 10 years

Two instruments onboard:

- **Large Area Telescope LAT (PI – Peter Michelson, Stanford University; managing organization - SLAC)**
  - **main instrument, gamma-ray telescope, 20 MeV - >300 GeV**
  - **scanning (main) mode - 20% of the sky all the time; all parts of sky for ~30 min. every 3 hours**
- **GLAST Burst Monitor GBM (PI – Charles Meegan, NASA/MSFC)**
  - **8 KeV – 40 MeV**
  - **observes whole unocculted sky all the time, searching for gamma-ray bursts**

Fermi LAT Collaboration

United States (NASA and DOE)

- *California State University at Sonoma*
- *Goddard Space Flight Center*
- *Naval Research Laboratory*
- *Ohio State University*
- *Stanford University (HEPL, KIPAC and SLAC)*
- *University of California at Santa Cruz – SCIPP*
- *University of Denver*
- *University of Washington*

France

- *CEA/Saclay*
- *IN2P3*

Italy

- *ASI*
- *INFN (Bari, Padova, Perugia, Pisa, Roma2, Trieste, Udine)*
- *INAF*

Japan

- *Hiroshima University*
- *Institute for Space and Astronautical Science / JAXA*
- *RIKEN*
- *Tokyo Institute of Technology*

Sweden

- *Royal Institute of Technology (KTH)*
- *Stockholm University*

122 full members

95 affiliated scientists

38 management, engineering and technical members

68 post-doctoral members

105 graduate students

Fermi Science Objectives

Fermi science objectives cover probably everything in high energy astrophysics:

- **Active Galactic Nuclei (AGN), including Extragalactic background light (EBL)**
- **Gamma-ray bursts (GRB)**
- **Pulsars**
- **Diffuse gamma-radiation**
- **EGRET unidentified sources**
- **Solar physics**
- **Origin of Cosmic Rays**
- **Dark Matter and New Physics**

Multiwavelength observations in cooperation with gamma-ray, X-ray, radio, and optical telescopes

Large Area Telescope LAT

Heritage from OSO-III, SAS-II, COS-B, and EGRET, but:

- large field of view (2.4 sr at 1 GeV, 4 times greater than EGRET) and large effective area (~8000 cm^2 on axis at 1 GeV)
- large energy range, overlapping with EGRET under 10 GeV and with HESS, MAGIC and VERITAS above 100 GeV, including poorly-explored 10 GeV – 100 GeV range.
- Good energy (<15% at E>100 MeV) and spatial resolution
  - Unprecendent PSF for gamma-rays, >3 times better than EGRET for E>1GeV
- Small dead time (<30 μs, factor of ~4,000 better than EGRET) – GRB time structure!
- Excellent timing (~ 1 μs) to study transient sources
- No consumables – chance for longer mission!

see for details Atwood, W. B. et al. 2009, ApJ arXiv:0902.1089v1

The LAT Instrument Overview

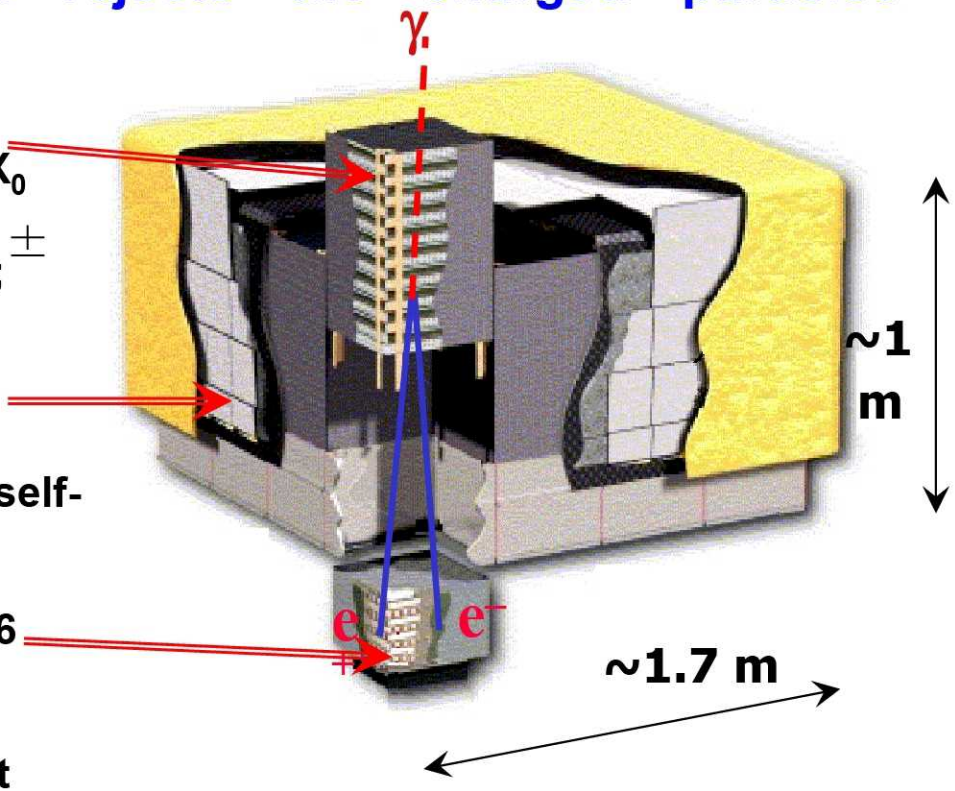
Pair-conversion gamma-ray telescope: 16 identical "towers" providing conversion of γ into e^+e^- pair and determination of its arrival direction (Tracker) and energy (Calorimeter). Covered by segmented AntiCoincidence Detector which rejects the charged particles background

Silicon-stripped tracker: 18 double-plane single-side (x and y) interleaved with 3.5% X_0 thick (first 12) and 18% X_0 thick (next 4) tungsten converters. Strips pitch is 228 μm; total 8.8×10^5 readout channels

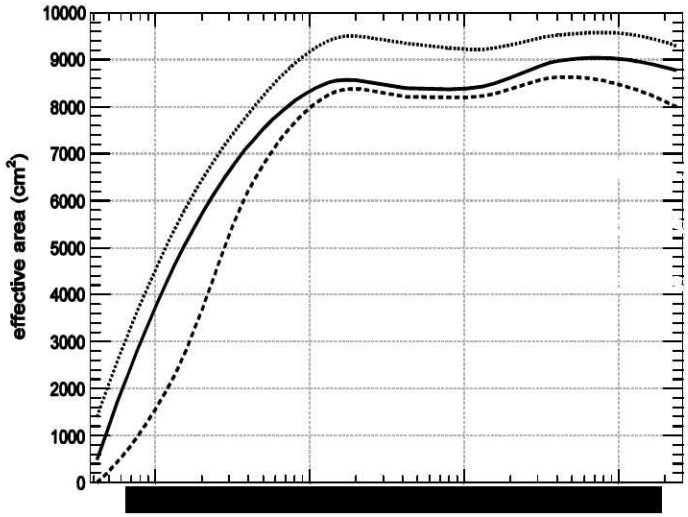
Segmented Anticoincidence Detector: 89 plastic scintillator tiles and 8 flexible scintillator ribbons. Segmentation reduces self-veto effect at high energy.

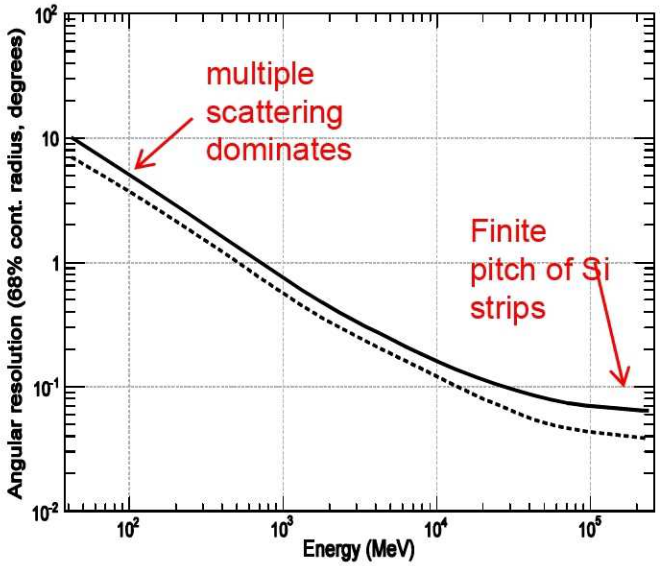
Hodoscopic CsI Calorimeter Array of 1536 CsI(Tl) crystals in 8 layers.

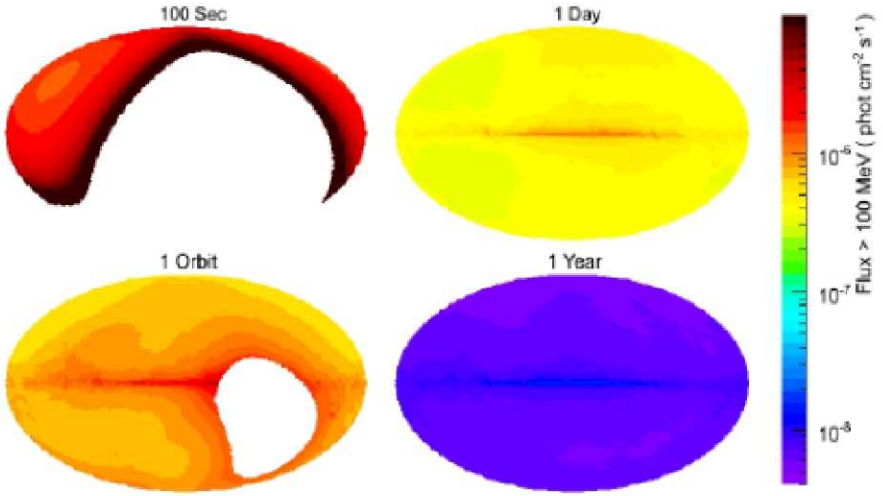
Electronics System Includes flexible, robust hardware trigger and software filters.



LAT Performance







Sensitivity to point sources

	Years	Ang. Res. (100 MeV)	Ang. Res. (10 GeV)	Eng. Rng. (GeV)	$A_{eff}\,\Omega$ (cm² sr)	# γ-rays
EGRET	1991–00	5.8°	0.5°	0.03–10	750	1.4×10^6/yr
AGILE	2007–	4.7°	0.2°	0.03–50	1,500	4×10^6/yr
Fermi LAT	2008–	3.5°	0.1°	0.02–300	25,000	1×10^8/yr

Main results for the first 8 months

- pulsars
- flaring AGN
- GRB
- diffuse radiation
- LMC
- electron spectrum

Papers:

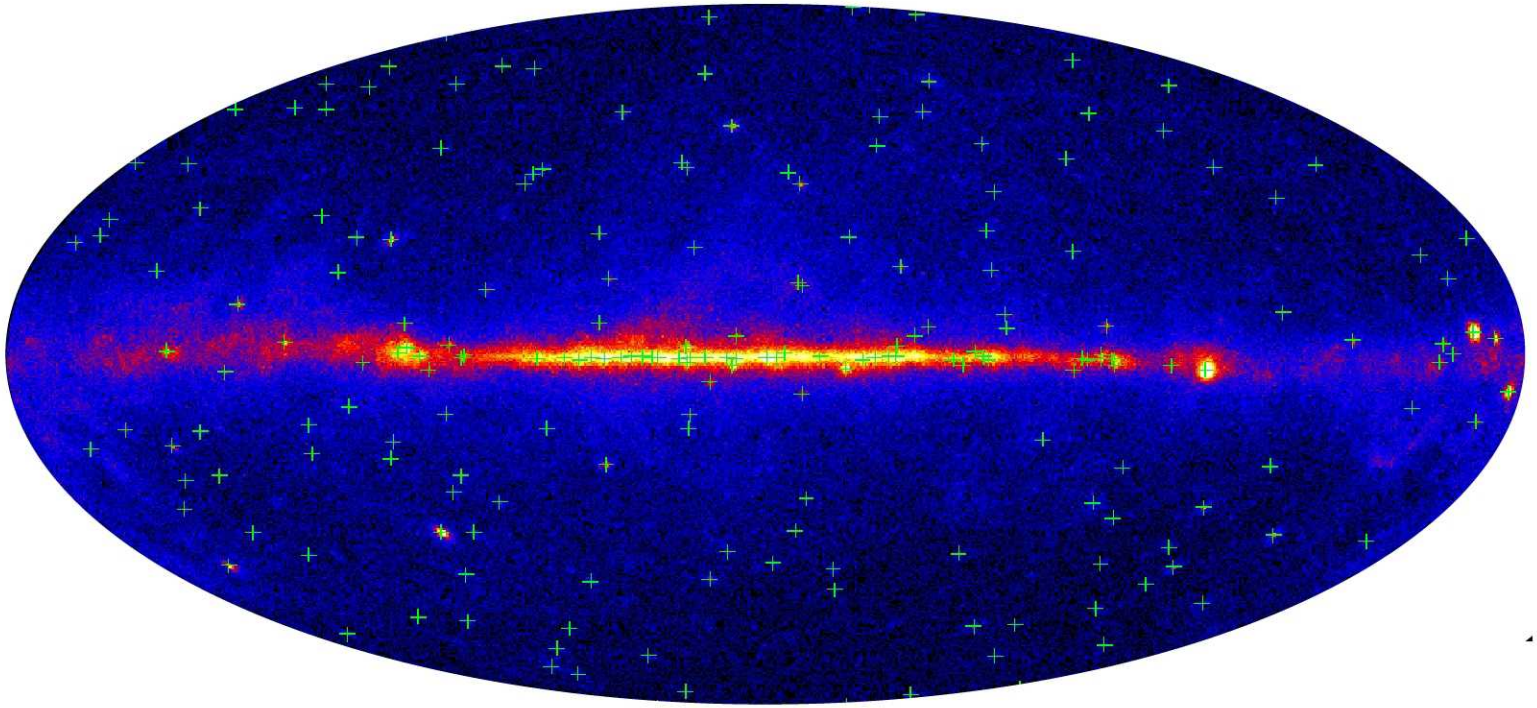
Submitted -

Accepted -

Published -

LAT 3 month sky map

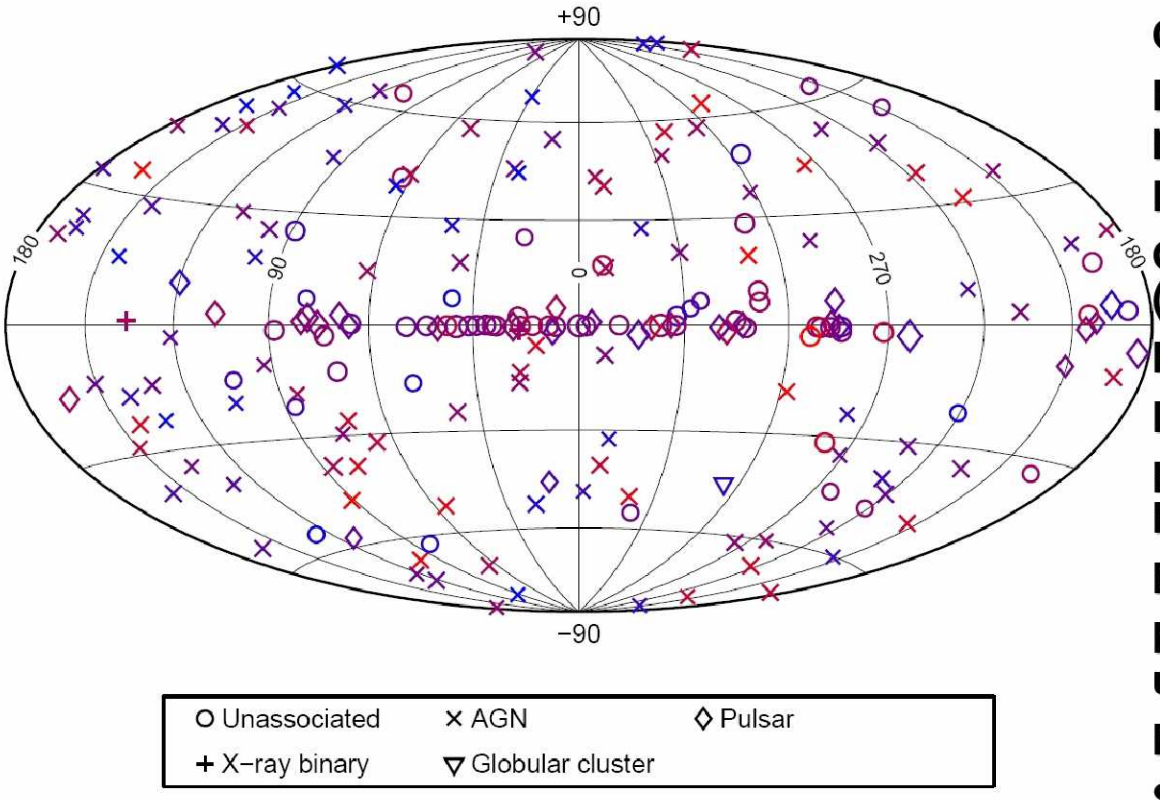
205 bright sources (sig. > 10σ). Paper submitted to ApJ Suppl.



Crosses mark source locations, in Galactic coordinates. 1/3 at |b| < 10°. Only 60 clearly associated with 3EG EGRET catalog. The sky changes!

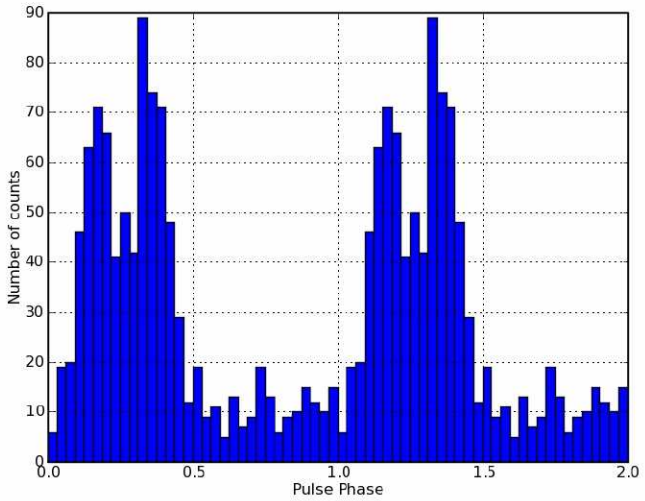
LAT bright sources

- based on first 3 months of sky-survey

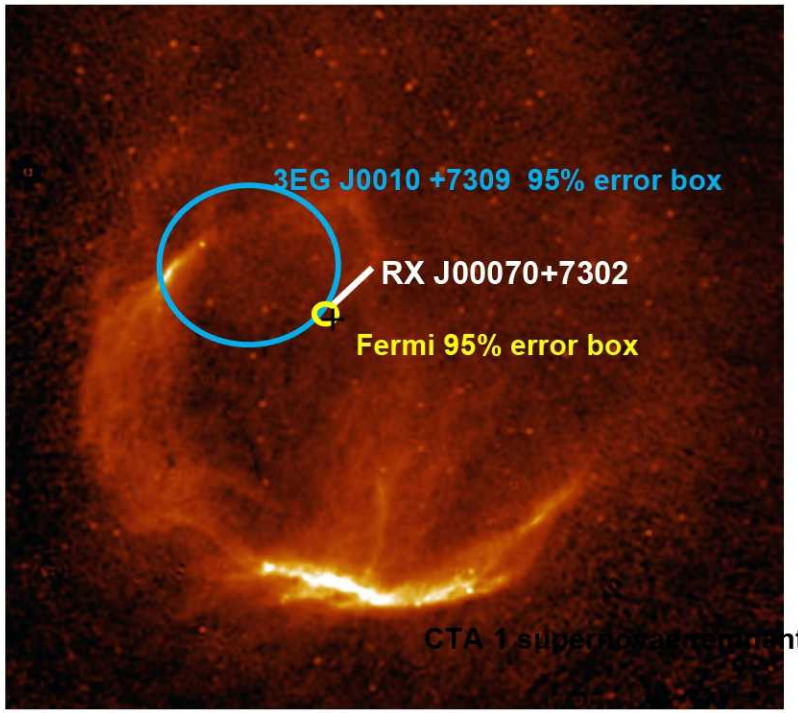


Class	Number
Radio/X-ray pulsar	15
LAT pulsar	14
Globular cluster (pulsars?)	1
HMXB	2
LMC	1
Flat Spectrum Radio Quasars	62
Bl Lac Objects	46
Blazar, uncertain type	11
Radio galaxies	2
Special cases (under study)	14
Unassociated	37

CTA1 - First gamma-pulsar detected by Fermi in blind search



+



- exhibits all characteristics of a young high-energy pulsar (characteristic age ~1.4 x 10^4 yr), which powers a synchrotron pulsar wind nebula embedded in a larger SNR.

- spin-down luminosity ~10^{36} erg s^{-1}, sufficient to supply the PWN with magnetic fields and energetic electrons.

- γ-ray source at *l,b* = 119.652, 10.468; 95% error circle radius =0.038° contains the X-ray source RX J00070+7302, central to the PWN superimposed on the radio map at 1420 MHz·

- pulsar off-set from center of radio SNR; rough estimate of the lateral speed of the pulsar is ~450 km/s

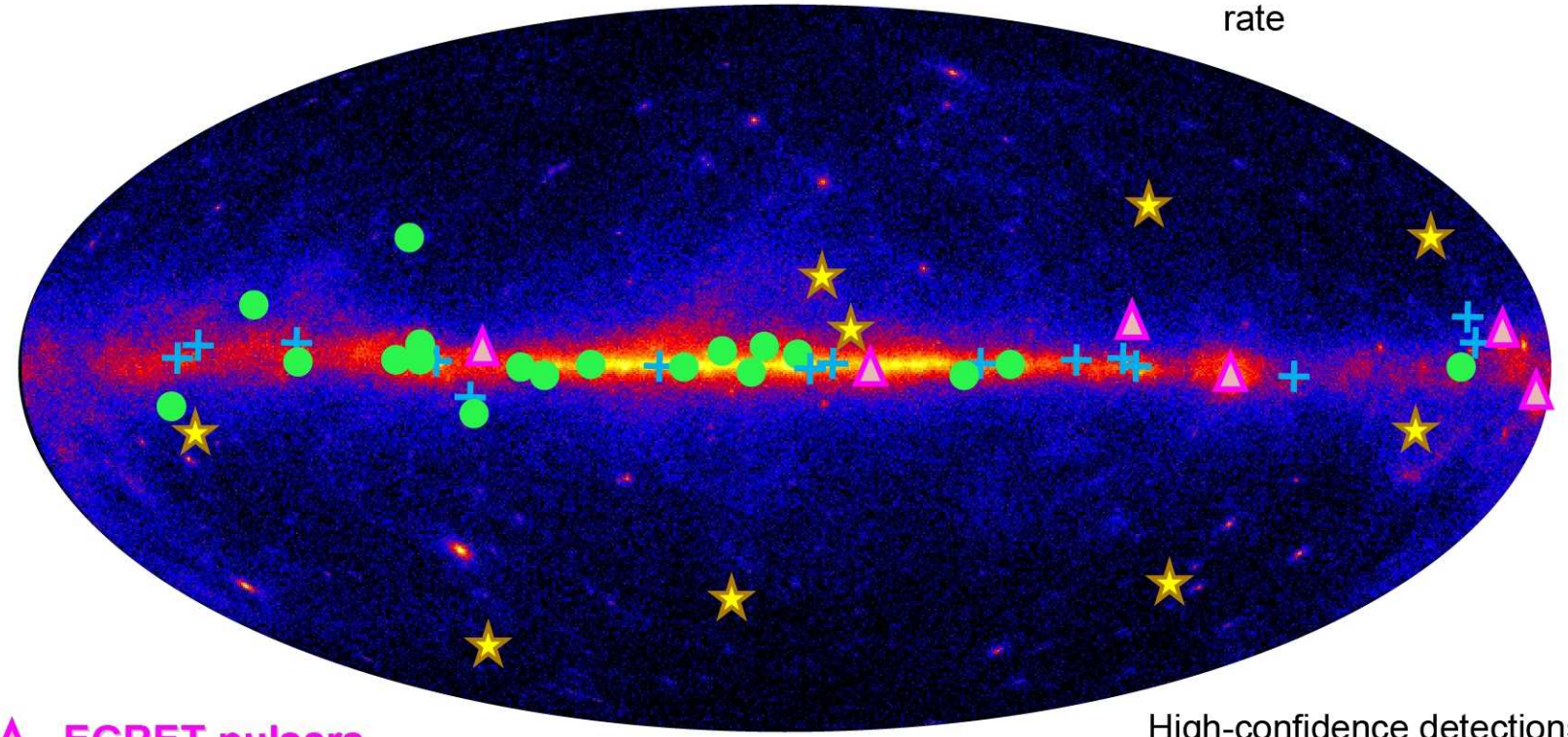
Science, November 21, 2008, v.322, 1218

Fermi pulsars

33 gamma-ray and radio pulsars (including nine ms psrs)

16 gamma-ray only pulsars

Pulses at 1/10th real rate



△ EGRET pulsars

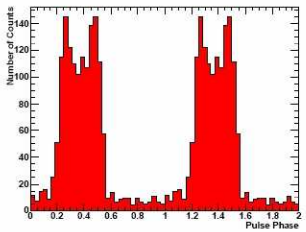
\+ young pulsars discovered using radio ephemeris

● pulsars discovered in blind search

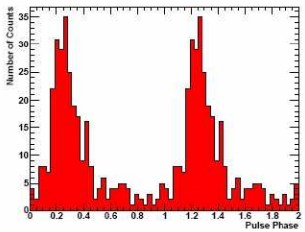
☆ millisecond pulsars discovered using radio ephemeris

High-confidence detections through 2/28/2009

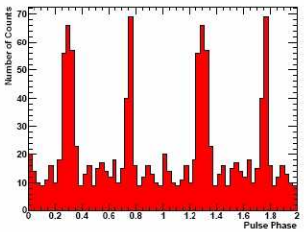
Blind search γ-ray pulsar light curves



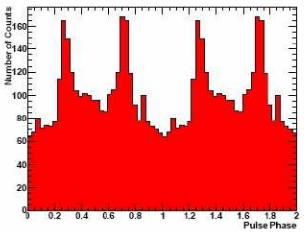
(a) LAT PSR J0007+7303



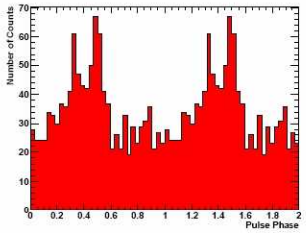
(b) LAT PSR J0357+32



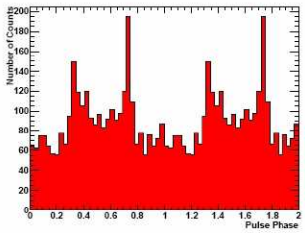
(c) LAT PSR J0633+0632



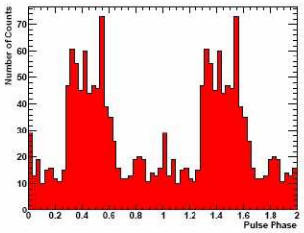
(d) LAT PSR J1418-6058



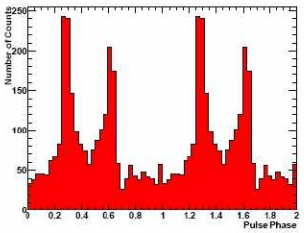
(e) LAT PSR J1459-60



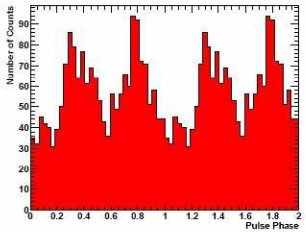
(f) LAT PSR J1732-31



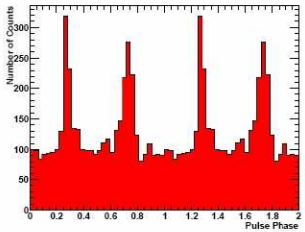
(g) LAT PSR J1741-2054



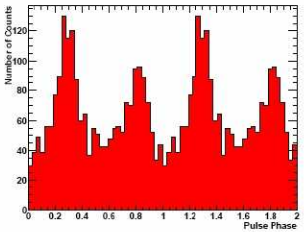
(h) LAT PSR J1809-2332



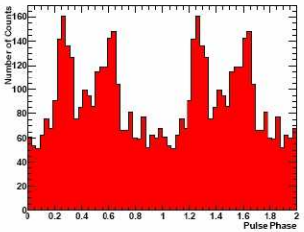
(i) LAT PSR J1813-1246



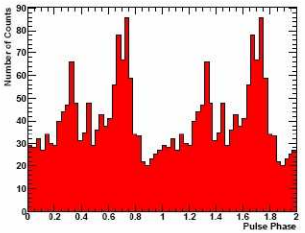
(j) LAT PSR J1826-1256



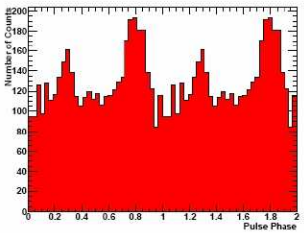
(k) LAT PSR J1836+5925



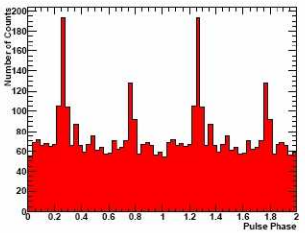
(l) LAT PSR J1907+06



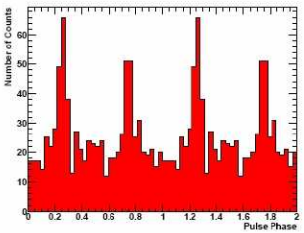
(m) LAT PSR J1958+2846



(n) LAT PSR J2021+4044



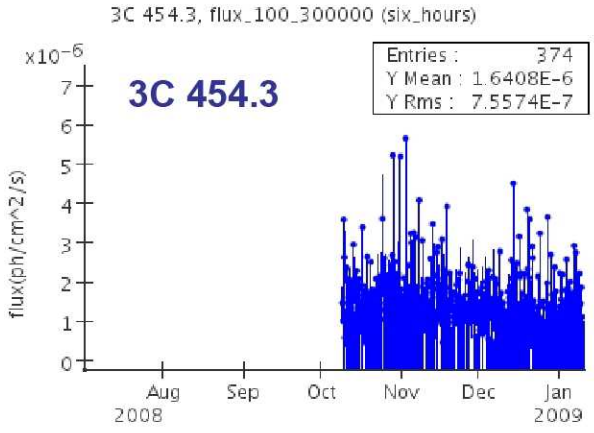
(o) LAT PSR J2032+4127

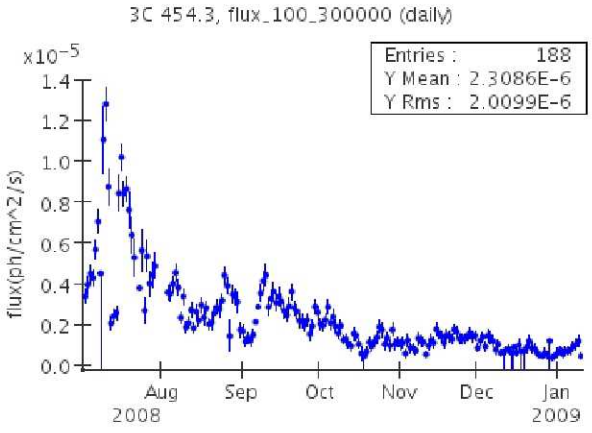


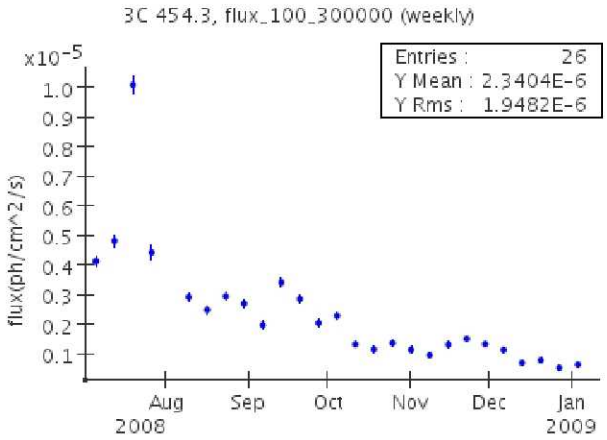
(p) LAT PSR J2238+59

Source Monitoring Activities

- **Automated Science Processing (ASP)**
  - *Follow-up monitoring: Runs full likelihood analysis on list from source detection step + "Data Release Plan" (DRP) sources*
  - *Transient detection: Uses source detection (pgwave) to find all point sources in data from each epoch (6hr, day, week)*
  - *2×10^{-6} ph cm^{-2} s^{-1} threshold (daily) for public release of non-DRP*
- *Flare Advocates:*
  - *LAT scientists from Galactic and Extragalactic groups examine output from ASP pipeline and perform follow-up analyses, produce ATels, and propose ToOs*







Fermi Gamma-ray Space Telescope

The Astronomer's Telegram

for reporting and commenting on new astronomical observations

- *Announcements of flaring sources ⇒ multiwavelength follow-up*
- *25 blazar-related LAT ATELs have been issued since launch on 22 different sources*

GLAST-LAT detection of extraordinary gamma-ray activity in 3C 454.3

ATel #1628; *G. Tosti (Univ/INFN-Perugia) , J. Chiang (SLAC), B. Lott (CENBG/Bordeaux), E. do Couto e Silva (SLAC), J. E. Grove (NRL/Washington), J. G. Thayer (SLAC) on behalf of the GLAST Large Area Telescope Collaboration*

on ***24 Jul 2008; 14:25 UT***

Password Certification: Gino Tosti (tosti@pg.infn.it)

Subjects: Gamma Ray, >GeV, AGN, Quasars
Referred to by ATel #: 1634, 1849

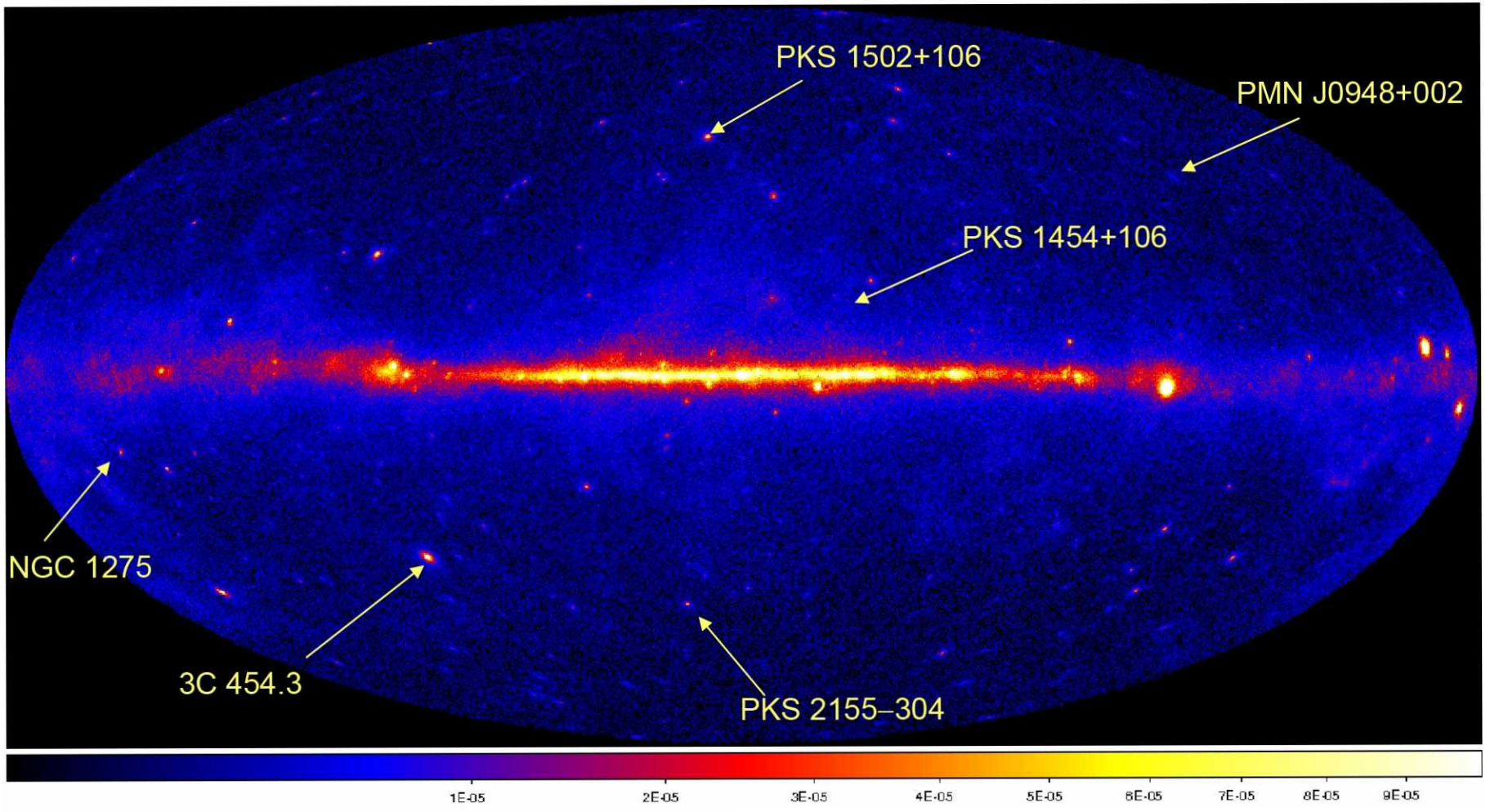
The Large Area Telescope (LAT), one of two instruments on the Gamma-ray Large Area Space Telescope (GLAST) (launched June 11, 2008), which is still in its post-launch commissioning and checkout phase has been monitoring extraordinarily high flux from the gamma-ray blazar 3C 454.3 since June 28, 2008. This confirms the bright state of the source reported by AGILE (see ATel #1592) and by the optical-to-radio observers of the GASP-WEBT Project (ATel #1625).

3C 454.3 has been detected on time scales of hours with high significance (> 5 sigma) by the LAT Automatic Science Processing (ASP) pipeline and the daily light curve (E>100 MeV) indicates that the source flux has increased from the initial measurements on June 28. Although in-flight calibration is still ongoing, preliminary analysis indicates that in the period July 10-21, 2008 the source has been in a very high state with a flux (E>100MeV) that is well above all previously published values reported by both EGRET (Hartman et al. 1999, ApJS, 123,79) and AGILE (see e.g. ATel #1592 and Vercellone et al. 2008, ApJ,676,L13).

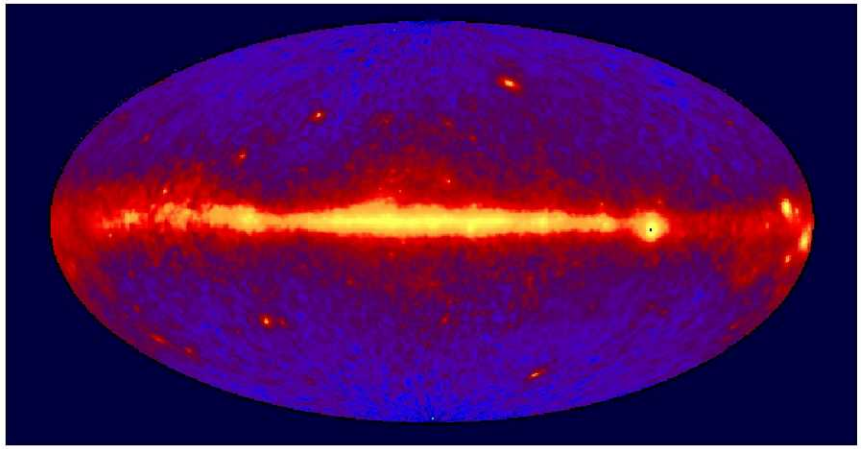
Multiwavelength Campaigns

- *3C 454.3: Jul-Oct; radio, opt, UV, Swift*
- *BL Lac: 15 Aug-5 Sep; opt, UV, X-ray*
- *PKS 2155-304: 25 Aug-6 Sep; radio, opt, UV, X-ray, TeV (HESS)*
- *1ES 1959+650: Sep-Nov*
- *PKS 0528+134: 27 Sep-Oct; radio, IR, opt, UV, X-ray*
- *3C 273: 31 Oct-7 Feb; radio, opt, X-ray*
- *3C 279: Aug—Mar; radio, opt, X-ray, TeV*
- *Mrk 421: Jan-May; radio, opt, X-ray, TeV (VERITAS, MAGIC)*

Fermi Results for Individual AGNs



Diffuse radiation: EGRET "GeV excess"



EGRET observations showed excess emission > 1 GeV when compared with conventional model tuned to reproduce local cosmic-ray nuclei and electron spectra

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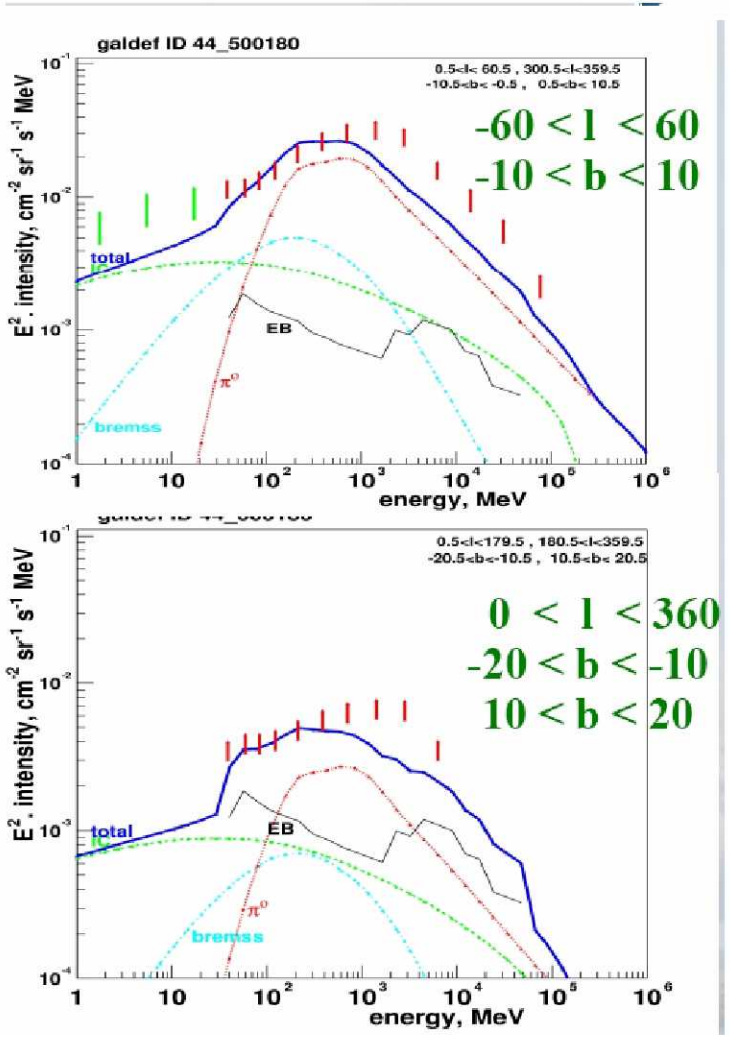
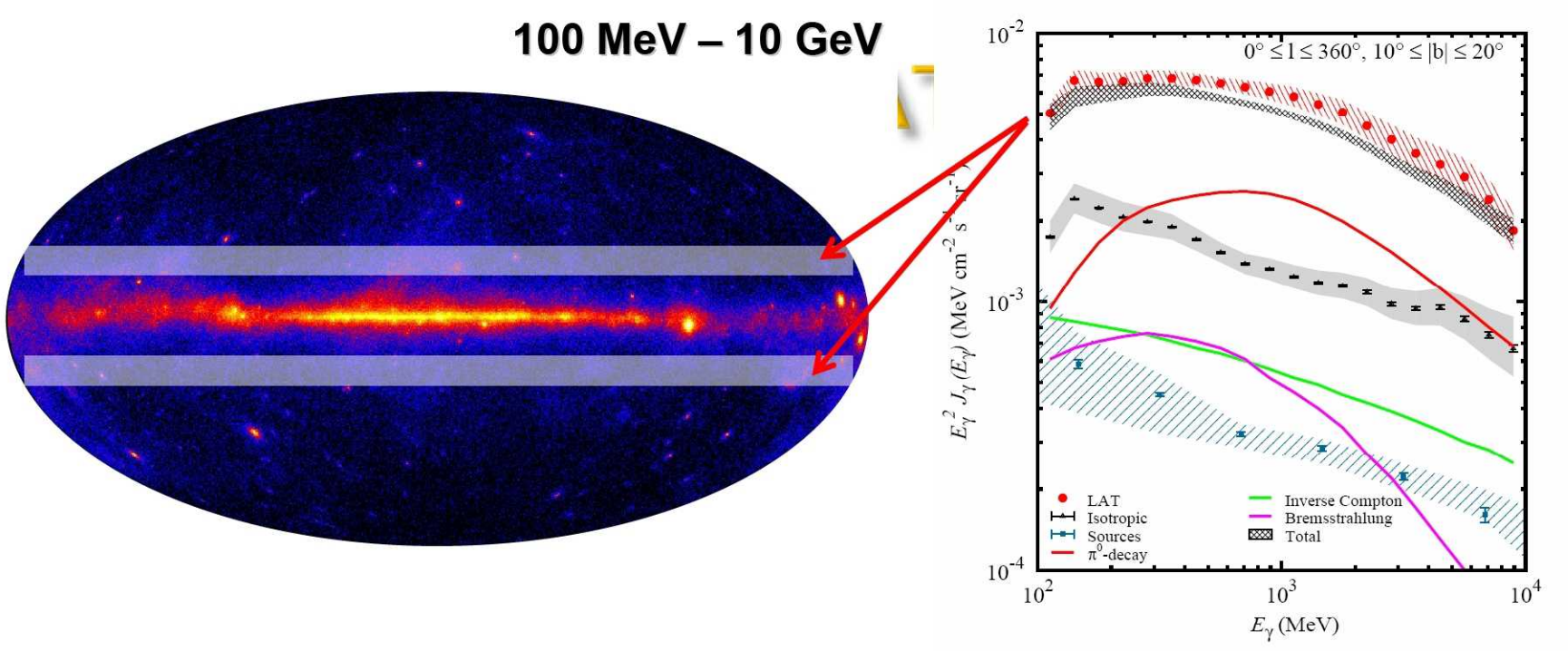


- Variety of explanations
  - Variations in cosmic-ray spectra over Galaxy
  - Unresolved sources (pulsars, SNRs, …)
  - Dark matter
  - Instrumental

~100% discrepancy > 1 GeV

Fermi result



- Spectra shown for mid-latitude range → EGRET GeV excess in this region of the sky is <u>not</u> confirmed
- Sources are a minor component
- LAT errors are systematics dominated and estimated ~10%
- Work to analyse and understand diffuse emission over the entire sky and broader energy range is in progress

Gamma-ray bursts observed by Fermi

- **LAT has reported 6 high-energy bursts since launch**

long-duration bursts

GRB 080825C: Fermi-LAT observations

SOURCE: GCN
TITLE: GCN CIRCULAR
NUMBER: 8183
SUBJECT: GRB 080825C: Fermi-LAT observations
DATE: 08/09/05 17:45:46 GMT
FROM: Aurelien Bouvier at Stanford <bouvier@stanford.edu>

GRB 080916C: Fermi LAT observation — Tajima et al. GCN 8246

SOURCE: GCN
TITLE: GCN CIRCULAR
NUMBER: 8246
SUBJECT: GRB 080916C: Fermi LAT observation
DATE: 08/09/16 18:25:23 GMT
FROM: Nicola Omodei at INFN(Pisa)/GLAST <nicola.omodei@pi.infn.it>

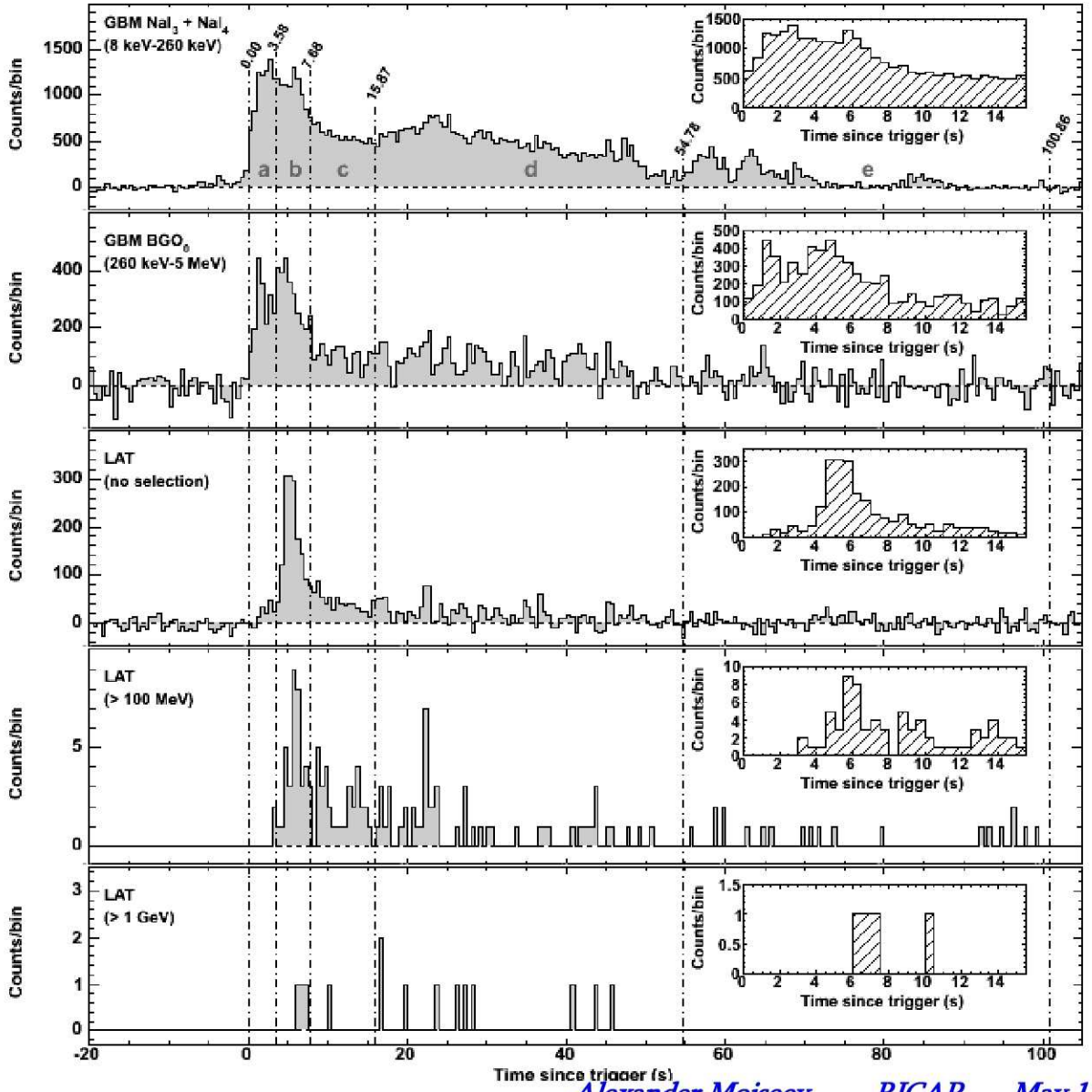
Z = 4.35 ± 0.15

First detection of short-duration burst at high energy

Fermi-LAT observation of GRB 081024B — Omodei GCN 8407

SOURCE: GCN
TITLE: GCN CIRCULAR
NUMBER: 8407
SUBJECT: Fermi-LAT observation of GRB 081024B
DATE: 08/10/25 14:07:58 GMT
FROM: Nicola Omodei at INFN(Pisa)/GLAST <nicola.omodei@pi.infn.it>

Light curves: high energy!



- For the first time, can study time structure > tens of MeV.
- Feature in the LC:
  - —pulse in interval "a" disappears at LAT energies.

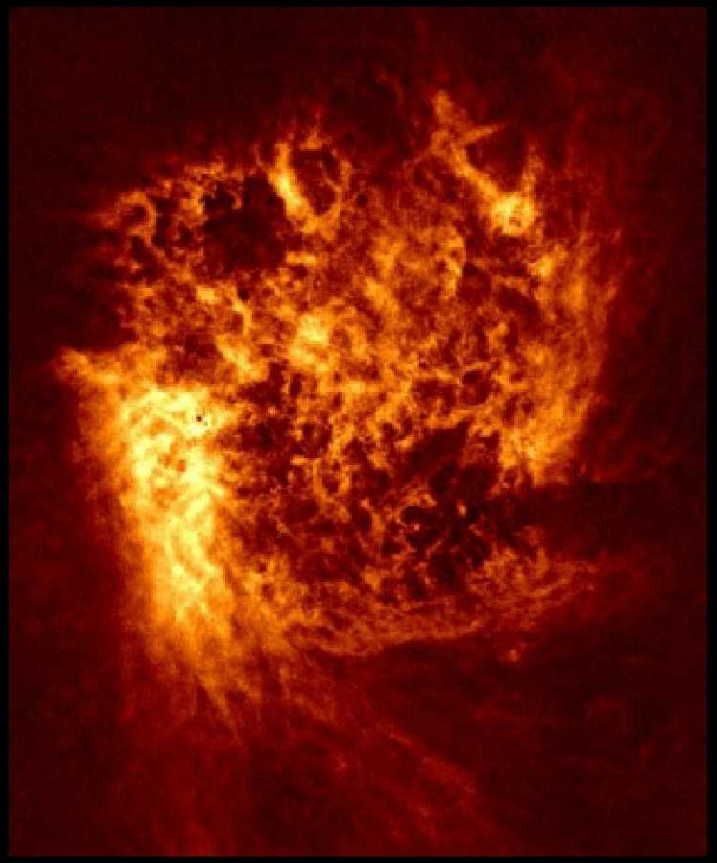
For this burst, $\gamma\gamma$ absorption arguments provide a stringent lower limit of $\Gamma_{min} = 860$

Science Express, 19 Feb 2009, pg 1

Why study the Large Magellanic Cloud?

NASA/JPL-Caltech/M. Meixner (STScI) & the SAGE Legacy Team

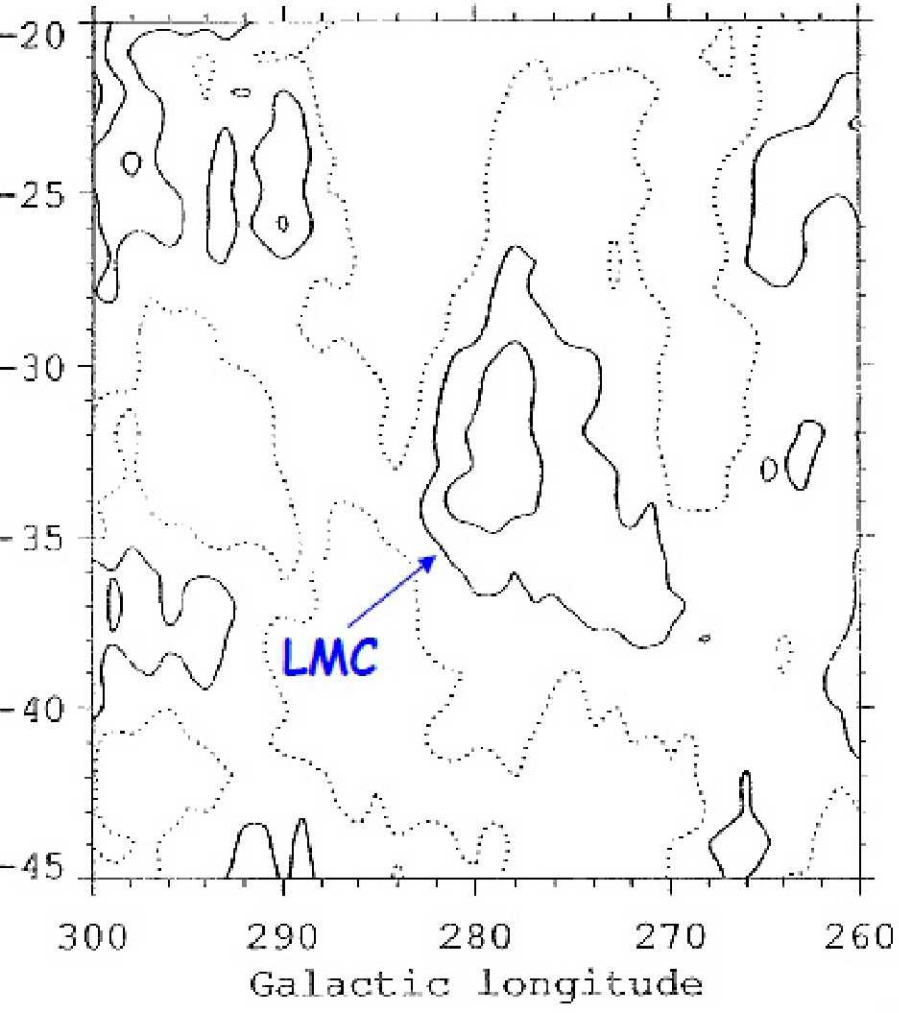
LMC is
- seen ~ face-on (i ≈ 27°)
- nearby (~ 50 kpc)
- active (many massive star forming regions)

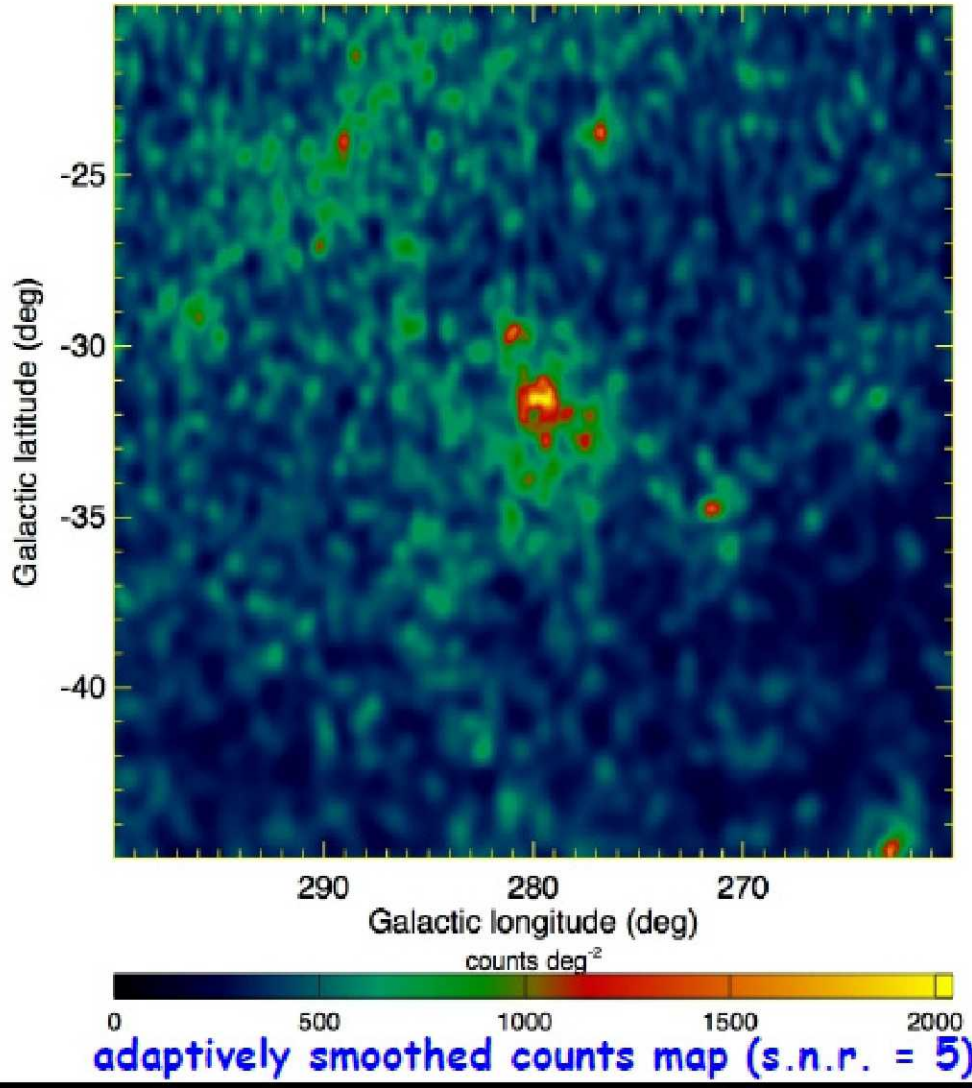


ATCA+Parkes H I (Kim et al. 2003)

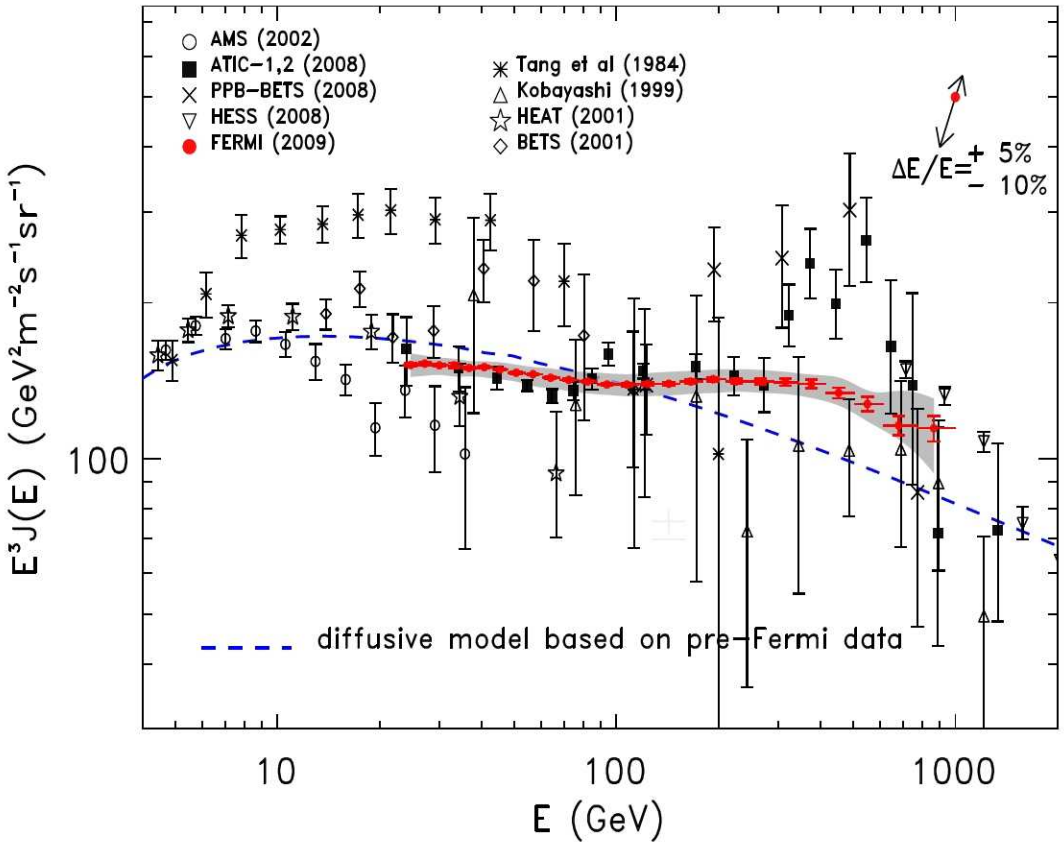
EGRET vs. Fermi View of LMC

PRELIMINARY





Fermi-LAT electron spectrum from 20 GeV to 1 TeV



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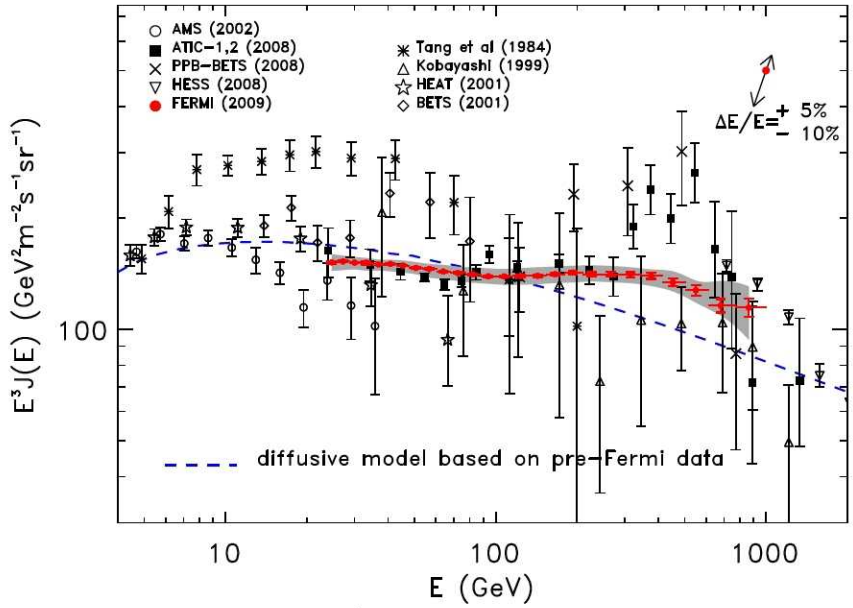
Total statistics *collected for 6 months of Fermi LAT observations*

- *> 4 million electrons above 20 GeV*
- *> 400 electrons in last energy bin (770-1000 GeV)*



- *The measured spectrum is compatible with a power law within our current systematic errors. The spectral index (-3.04) is harder than expected from previous experiments and simple theoretical considerations*
- *"Pre-Fermi" diffusive model requires a harder electron injection spectrum (by 0.12) to fit the Fermi data, but inconsistent with positron excess reported by Pamela if it extends to higher energy*
- *Additional component of electron flux from local source(s) may solve the problem; its origin, astrophysical or exotic, is still unclear*
- *Valuable contribution to the calculation of IC component of diffuse gamma radiation*

- *Fermi Gamma-ray Space Telescope fully operational..*
- *In first few days of sky survey, the LAT corroborated many of the great discoveries of EGRET; now finding new sources as well;*
- *With 6 months of the 1st year all-sky survey phase;*
  - *large number of pulsars detected, many only in g-rays;*
  - *many flaring active galaxies observed; about half not seen by EGRET;*
  - *Flaring sources observed along the galactic plane;*
  - *High-energy emission seen from 6 GRBs; first time seen from short-duration burst;*
  - *Quiescent sun detected at high energies;*
  - *Major progress in understanding galactic diffuse emission*
- *With time, Fermi will probe deeper and deeper into the high-energy* **Universe**